CIPHER MESSAGES FROM THE STARS*

By J. H. Moore

Some months ago it was reported in the daily press that certain unfamiliar signals were being received at several wireless stations, and there was much speculation as to their origin. One of the most fantastic of these suggestions, and one which attracted wide attention, was that the strange messages were radio signals from *Mars*. While the Martian signals have no foundation in fact, it is true, nevertheless, that in our great observatories we are receiving messages from the stars, transmitted by electro-magnetic waves, differing from those of wireless telegraphy only in the length of the waves. In ordinary radio work the wave-length employed is of the order of a few thousand feet, whereas the light waves which bring us the news from the stars have lengths between about one thirty-thousandth and one eighty-thousandth of an inch. These stellar light waves, when received by a spectrograph, write a wonderful message, which, to the uninitiated, appears as nothing more than a few bright or dark lines on the photographic plate. But when we hold the key to the cipher it is readily translated, and altho it may have been hundreds or thousands of years in reaching us, there can be no question of the validity of its origin or interpretation.

In the preceding lecture you were told about the spectroscope or spectrograph as it is called when the observations are photographic, and of the fundamental principles of spectrum analysis, built up little by little in the physical laboratory thru a long series of brilliant researches. These principles furnish the basis or code for the interpretation of the cipher messages which we shall consider this evening, and they may be briefly summarized as follows:

(1) When the slit of a spectroscope is illuminated by light from an incandescent solid or glowing gas under high pressure the spectrum consists of an unbroken band of color; that is, a continuous spectrum.

(2) An incandescent gas or vapor under low pressure gives a spectrum consisting of isolated bright images of the slit, the bright lines indicating that radiations of certain definite wave-lengths are emitted by the gas. Each chemical element in the gaseous state, when rendered luminous in the electric arc, electric spark, flame or

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vacuum tube, gives its own set of bright lines, which are characteristic of this element alone and whose wave-lengths remain constant for a source at rest under the same conditions of temperature and pressure.

(3) An incandescent gas has the property not only of radiating waves of certain definite lengths, but also of absorbing from white light passing thru it the rays of precisely those same wave-lengths. If the temperature of the incandescent gas is lower than that of the source behind it, the continuous spectrum will be crossed by relatively dark lines, whose positions agree exactly with those of the bright-line spectrum characteristic of the gas.

These three principles obviously lead to a simple and direct method of analyzing the chemical constituents of gaseous light sources and of furnishing information as to their physical condition. When the light from the Sun, for example, is examined with the spectroscope its spectrum is seen to consist of a band of color crossed by many dark lines, whose positions coincide with those of the bright lines of many of the chemical elements obtained in the laboratory, thus indicating that the light of the Sun emitted by a central glowing core, has passed thru a surrounding atmosphere of cooler vapors.

The dark lines of the solar spectrum have been compared with the bright line spectra of the known elements, by means of very powerful grating spectrographs, and the presence in the Sun of thirty-eight of the chemical elements has certainly been established. Most of these, such as hydrogen, sodium, calcium, barium, magnesium, iron, titanium, copper, tin, lead and zinc, occur in more or less abundance in the accessible portions of the Earth. The presence of oxygen and nitrogen in the Sun is also to be inferred from the identification of certain solar lines with those of compounds of these elements, altho the line spectrum of neither one appears to be represented. None of the lines of the heavier elements, gold, platinum, iridium, and others, have as yet been identified in the solar spectrum.

The surface of the Sun when examined with a telescope exhibits a number of interesting details, among which are the well known sun-spots. Since the invention of the telescope these spots have been carefully studied by many observers and a mass of data has been accumulated concerning their appearance, location and motion on the Sun's surface, and the rapid changes in their form and size which frequently occur. It was from studies of this char-

acter that the rotation period of the Sun was determined and that the periodicity in the occurrence of sun-spots was discovered, soon followed by the recognition of the close connection existing between these solar disturbances and terrestrial magnetic storms. Valuable as was the information obtained in this way, it remained, however, for the spectroscopic method to give us the real insight into the nature of the phenomenon. When one of the spots is placed on the slit of the spectroscope and its spectrum compared with that of the Sun's surface, it is seen that many of its lines appear darker, and others fainter than in the ordinary spectrum ot the Sun. These effects for the particular lines in question are obtained in the laboratory when the temperature of the absorbing vapor is lowered. In addition, the bands due to titanium oxide are found in the spot spectrum, altho they do not appear in that of the Sun, since the temperature of the latter is too high for the existence of this compound. We have then undoubted evidence that the vapors in sun-spots are cooler than those of the surrounding portions of the Sun, but their temperatures are higher than that of the electric arc.

A few years ago Professor St. John, of the Mount Wilson Observatory, showed from the displacement of the lines in the spectrum of a sun-spot, in accordance with a principle to be discussed later, that the vapors situated at low levels in the spot were moving outward, while the cooler vapors in the upper regions were being drawn into the spot. In addition to obtaining important information concerning the mechanism of sun-spots, he was able to utilize these data as a sounding rod in determining the different levels at which the various chemical elements are distributed in the solar atmosphere.

The ordinary visual or photographic image of the Sun is a composite formed by light of different wave-lengths and originating at various depths in the solar envelope. Obviously in such an image one would obtain no indication of the complex motion in a sun-spot revealed by the spectroscope. If, however, we were able to photograph the Sun in the light of one single spectrum line, for example one of the lines of hydrogen, we should have a method of revealing the actual distribution of hydrogen over the Sun's surface, at this particular time. By a simple modification of the spectroscope, Professor Hale, then at the Kenwood Observatory, and independently, and somewhat later Deslandres of the Paris Observatory, devised a method by which this is accomplished. In principle it

consists of admitting the light from one line in the solar spectrum thru a narrow opening, in front of the photographic plate, then moving the Sun's image across the slit of the spectrograph and at the same rate moving the photographic plate. The instrument employed is known as a spectroheliograph and, in the hands of Professor Hale and his colleagues, it has proved one of the most powerful and fruitful for solar research. Photographs of sun-spots secured with the spectroheliograph, utilizing the light of one particular line of hydrogen or calcium show the great whorls of these vapors centering about the spot, a vortex or cyclone on a gigantic scale. Moreover, on plates separated by short intervals of time the cooler vapors in the upper levels are at times seen in the process of being drawn into the spots.

Reference was made in the preceding lecture to the discovery, by Professor Hale, of the Zeeman effect in sun-spots, or that the spectral lines in the central portion of a spot are separated into two components, showing that a sun-spot is the source of a magnetic field and that we are viewing the light in the direction of the field. More recently he has proved by a similar method of observation that the Sun itself is a great magnet with the magnetic axis nearly coincident with the axis of rotation. The reason for the close relation between terrestrial magnetic disturbances and solar phenomena has thus been revealed thru the interpretation of a cipher message from our star.

All of the information we have concerning the corona, a portion of the Sun visible only at the time of a total solar eclipse, has been gathered in the few precious moments of totality. Nevertheless, the spectroscope has contributed a most important part to our knowledge of this strange solar appendage. The inner corona gives a continuous spectrum, upon which are superimposed several bright lines, one in the green being particularly strong. These lines do not belong to any known terrestrial element and, as they are found only in the corona, the hypothetical element giving them is called coronium. The spectrum of the outer portions of the corona shows the familiar Fraunhofer lines. This, together with the fact that its light is radially polarized, furnishes strong evidence that the outer corona consists chiefly of small particles or gas molecules shining by reflected sunlight.

At the time of a total eclipse of the Sun several crimson prominences are generally to be seen, in some instances reaching to the

height of a hundred thousand miles above the solar surface. A number of years ago an eclipse observer noted in the spectrum of one of these prominences a bright yellow line near the two D lines of sodium. Lockyer was the first to recognize that this line belonged to no known terrestrial substance and he gave to the element producing it the name of helium, from the Greek word, helios, for the Sun. Twenty years later Ramsay found helium in the chemical laboratory. It is only twice the density of hydrogen and possesses the property of not combining with other elements. This makes it an ideal substance for filling balloons, especially in time of war. So rare is this element on the Earth that previous to the World War not more than a few hundred cubic feet of helium had been collected, and at a value of about $1,700 per cubic foot. When the armistice was signed the United States had ready for shipment to France 147,000 cubic feet of this gas collected from the oil wells of Texas and Oklahoma at a cost of only ten cents per cubic foot, and plans were under way for its collection at the rate of 50,000 cubic feet a day. We may thus say that a great advance in aerial navigation had its origin in the discovery of a bright yellow line in the spectrum of a solar prominence.

On account of their enormous distances from us the images of all stars even in our greatest telescopes are mere points, so that we can not hope to gain any information concerning the surface details of a star as we have in the case of the Sun. For the same reason the light of even the brighter stars is to us very feeble in comparison with that of the Sun, rendering it desirable to use a large telescope, in order to collect as much of their light as possible. Furthermore, as all spectrographs are very wasteful of light, it becomes a matter of prime importance to select the one which is the most efficient in this respect. We are therefore generally limited to the use of a prism spectrograph in our analysis of the light of celestial sources.

The equipment of large observatories engaged in stellar spectroscopy usually includes several of these prism spectrographs, each adapted for its own special class of work. As an illustration of the general form and arrangement of such instruments we may select the Mills three-prism spectrograph of the Lick Observatory, shown in the accompanying reproduction, Plate I, mounted on the 36-inch refractor. Light from a star is brought to a focus by the large objective upon a narrow slit, one or two thousandths of an inch in width, and, after passing thru the slit, falls upon the colli-

mator lens, from which it emerges as parallel rays. It then passes in turn thru the three prisms, by which it is turned from its original direction nearly 180°, rays of different colors or wave-lengths being deviated by different amounts. Finally an image of the spectrum is formed by the camera lens, on the photographic plate which is placed in the small holder shown in the illustration at the lower right portion of the white box. By means of a simple device the bright line spectrum of an element rendered luminous in an electric spark mounted on the spectrograph is photographed on each side of the stellar spectrum for comparison. Since the spectrum from the red to the violet formed by such an instrument would have a length of about two feet, it is practicable to utilize only a very short section of this and the one actually employed is a comparatively small region in the blue. With the Mills spectrograph the exposures range from a few minutes for the spectra of the brighter stars, to about four hours for those of stars just visible to the naked eye. In order to obtain spectra of still fainter stars it is necessary to use fewer than three prisms and be satisfied with the consequent reduction in power.

When the spectra of a number of stars are examined it is found that they exhibit a great variety in the number and character of their lines. Some fifty years ago Secchi observed the spectra of several hundred stars by means of a visual spectroscope, and concluded that it was possible to arrange all of them in one of four separate groups or types. While exhibiting very well the most prominent characteristics of stellar spectra, his system is insufficient for portraying the finer gradations revealed by the photographic plate. The classification now in general use was formulated by the late Professor Pickering, Miss Maury and Miss Cannon from the very extensive photographic survey of stellar spectra made by the Harvard College Observatory at Cambridge and at Arequipa, Peru. In their system the different classes are represented by letters. Thus we have the spectra of Class B characterized by the presence of only a few lines, in which those of helium are prominent; Class A in which the lines of hydrogen predominate; Class F characterized by the appearance of many of the so-called enhanced lines of the metals and the decreased intensities of the hydrogen lines; Class G with spectra like that of the Sun; Class K with spectra similar to the solar spectrum, but with some of the lines indicative of a lower temperature, and classes M and N with the lower temperature lines,

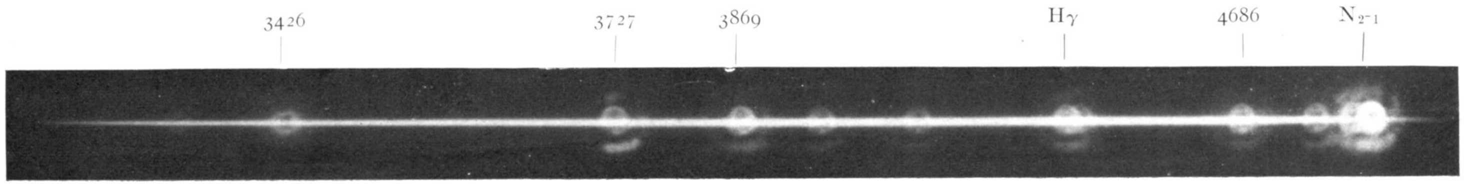


Figure *a*. N.G.C. 2392

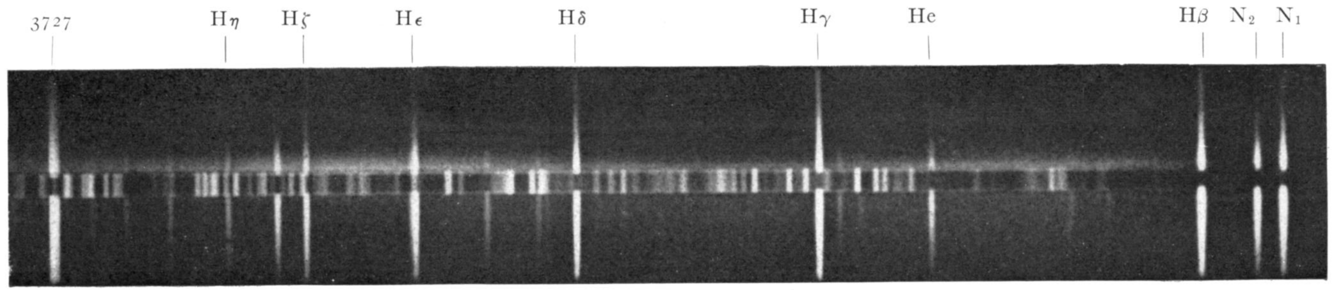


Figure *b*. Orion Nebula (Comparison spectrum at center)

PLATE II

the bands of titanium oxide predominating in the former and those of carbon in the latter.

The stars of Classes B and A are rich in blue light, those of Classes F and G in yellow, and the M and N stars in red. Since the law connecting the temperature and color emitted by a perfect radiator is known, it is possible from a determination of the maximum intensity in a star's spectrum, to estimate the effective surface temperature of the star. It is found that the descending scale of temperatures is from the Class B stars to those of Classes M and N. Are we here observing stars in different stages of the process of cooling? If so, it would appear that the blue stars are still young, that those like our Sun are in middle life, and that the M and N stars have reached old age. Many astronomers believe such to be the case, but by no means all of them. This phase of the story which the messages from the stars tell of their life history will be discussed in the final lecture of the course.

The opinion was held at one time that the large nebulae of greenish color, of which the Great Nebula in *Orion* is a typical example, would with sufficient telescopic power be resolved into myriads of stars. The message recorded by the spectrograph forever dismisses the hypothesis of the stellar constitution of these objects, since their spectra consist chiefly of bright lines emitted by incandescent gases. A spectrogram of the *Orion* nebula is reproduced in Plate II b, in which the long lines are those of the nebular spectrum, while the short ones of the central strip are produced by iron vapor in the electric spark. The positions of the familiar hydrogen lines are indicated by the letters $H\beta$, $H\gamma$, $H\delta$, etc., and those of helium are marked He. The two strong lines, N_1 and N_2, have not been found in laboratory spectra, nor in those of the Sun and stars, with the exception ot the novae or new stars, and of one very red star in which they were recently detected by Merrill. These lines are characteristic of all gaseous nebulae, both those of irregular form and the ones which from their disk-like appearance are termed planetary nebulae. To the unknown element associated with these two lines the name of nebulium has therefore been given. Since the width of the spectral lines given by these nebulae is ot the same order as that obtained in the vacuum tube spectra of gases, we have conclusive evidence that the gaseous nebulae are extremely tenuous objects, save as to the central stellar nuclei which exist in the most of them.

One of the most striking and significant illustrations of the information which the spectrographic method furnishes concerning the planetary nebulae is afforded by the very comprehensive investigation of these objects by Professor Wright. By dispensing with the slit of a quartz spectrograph, a small image of the nebula was obtained in the position of each of the usual nebular lines. The record, of which an example for the planetary nebula N.G.C. 2392 is seen in Plate II a, is a series of images of the nebula, each image formed by light of a definite wave-length. It indicates at once the relative distribution in the nebula of the radiations of the different constituent gases. Mr. Wright found that in general hydrogen is the most widely distributed element in the planetary nebulae, with nebulium next in order, whereas helium is confined more closely to the nuclear or central region; an order of distribution in accordance with that which might be expected from the relative densities of these gases.

Thus far the messages which we have been interpreting have dealt with the constitution and physical condition of celestial objects, or what may be termed the chemistry of the stars. The results have been presented from the standpoint of the observed coincidences between the dark lines of stellar spectra and the bright-line radiations emitted by the known elements, in accordance with the second principle of spectrum analysis stated above. Since light involves a wave motion propagated with a finite velocity, we know that the colors or lines which we have been observing are produced by light waves of different lengths. That is, the spectroscope has merely separated the waves of different lengths present in the star image, and arranged them in orderly array according to their wave-lengths, the violet waves being those of shorter length, while the red ones are the longer waves. The lengths of the waves corresponding to the lines obtained in the spectra of different elements have been accurately measured in the laboratory, so that we are able from the relative positions of the comparison lines (*i. e.*, from the spark or arc lines of a selected element) and those of the lines of the stellar spectrum to determine the wave-length of any line in the spectrum of a star. In other words the comparison lines on the spectrogram merely supply a series of reference wave-lengths. As light waves are extremely short, spectroscopists have for convenience chosen as the unit of wave-length the one ten-millionth of a millimeter, or one two hundred and fifty millionth of an inch. In this

unit, for example, the lengths of the waves of the hydrogen lines (on Rowland's scale) are: $H\alpha$ in the red 6563.015, $H\beta$ in the blue-green 4861.505, $H\gamma$ in the violet 4340.630, and $H\delta$ in the violet 4101.890. On the two stellar spectrograms reproduced in Plate III a and b, it will be seen that the dark lines of the stellar spectrum are not coincident in position with the bright iron lines of the electric spark. In the upper spectrogram the stellar lines are displaced toward the violet (left), which means that the iron radiations received from the star have shorter wave-lengths than the corresponding iron radiations from the electric spark. In the lower spectrogram the stellar light waves are longer than those of the corresponding comparison lines. The phenomenon here shown is known as the Doppler-Fizeau effect, and it is familiar to many of you in the case of sound waves. It is a fact of common observation, for example, that the pitch of a locomotive's whistle is higher when the locomotive is approaching and lower when it is receding from the observer than it is when the locomotive is at rest. In the first case the waves of sound are crowded together; in other words, the length of the wave is shortened and this corresponds to a higher pitch. For a receding source the sound wave received by the observer is lengthened and hence the pitch is lower. It is easily seen that the proportional amount of the shortening or lengthening of the sound wave is equal to the ratio of the speed of the locomotive to that of the propagation of sound. Thus, if we find that the wave is shortened by one-tenth of its original length, the locomotive is approaching us with the speed of one-tenth the velocity of sound (1100 feet per second) or 110 feet a second. With these facts in mind we are in a position to read a message recorded on our two spectrograms (Plate III a and b). Obviously the displacement of the lines of the stellar spectrum toward the violet (a) or the shortening of the light waves received from the star, means that the star is approaching us. Measurement of the wave-lengths of the stellar lines shows that they have been shortened, on the average, 1/7614 of the normal wave-lengths of the lines. Since the velocity of light is 186,000 miles per second, the relative velocity of the star and observer in the line joining them, *i. e.*, in the line of sight, is 24.4 miles per second. Similarly, the star whose spectrum is recorded on the second spectrogram (b) is receding with a velocity of 32.6 miles per second. In speaking of the motion of approach and recession of the stars, it should be understood that there are stars moving

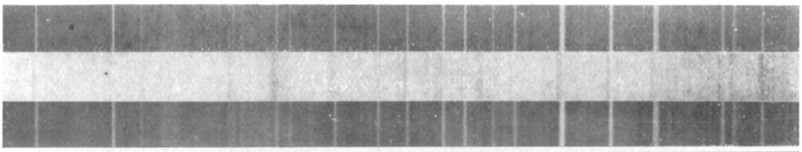
in all directions, and that we are here determining only that part of a star's velocity which is in the direction of the line of sight, or, as it is generally called, the star's radial velocity. Furthermore, a portion of the measured velocity arises from the observer's own motion toward or away from the star, due to the orbital revolution of the Earth and the Earth's rotation upon its axis. As these quantities are known they may be removed. The corrected result is the relative radial velocity of the star and the Sun. The values for the two spectrograms considered above after correction for the observer's motion in the Sun's system are respectively 31.7 miles per second of approach, and 22.3 miles per second of recession.

Since we are unable to determine the velocities of stars in the line of sight in any other way, it is important to submit the method to the test of measuring a known velocity. Fortunately we are able to do this in the case of the planets, whose orbits and velocities are well known. On a spectrogram of *Mars*, for example, the displacement of the spectral lines of the planet arises from the relative radial velocity of *Mars* and the Sun and from that of *Mars* and the Earth. The velocity of *Mars* as given by the measurement of a spectrogram usually agrees with that of computation within say 300 feet a second, which is about the limit of accuracy attainable with our present means.

In attaining the high accuracy demanded for the solution of astronomical problems, it is necessary to guard against spurious displacements of the spectral lines, such as would arise from flexure in the instrument or changes in the temperature of its optical and mechanical parts during the progress of the exposure. The Mills spectrograph (Plate I) was specially designed for this class of observation and rigid tests have shown that the instrument is free from flexure effects. The spectrograph is maintained at a constant temperature, during the night's work, by means of a surrounding case provided with an automatic heating device.

With the Mills spectrograph on Mount Hamilton and similar instruments at the Chile observing station of the Lick Observatory, at Santiago, the radial velocities have been obtained of all the stars brighter than visual magnitude 5.5 in the northern and southern heavens whose spectra contain measurable lines. This work was initiated at the Lick Observatory some twenty-five years ago by Professor Campbell, under whose immediate supervision the programs in the two hemispheres have been carried to completion.

a



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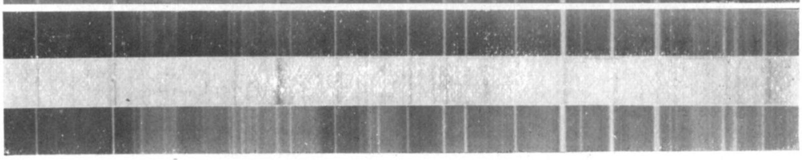

Figures *a* and *b*. Spectrograms of ι Pegasi

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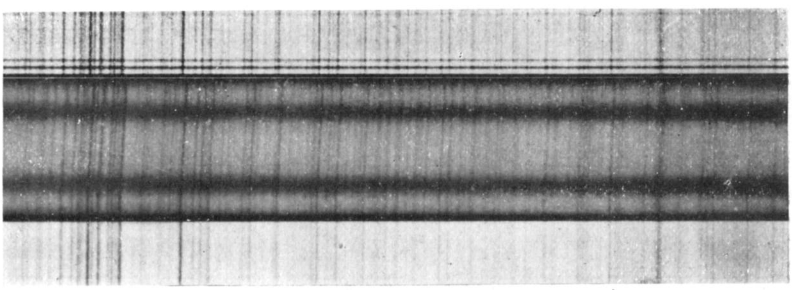

Figure *c*. Spectrogram of Saturn and Rings

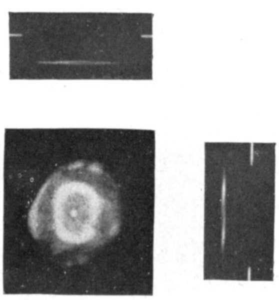

Figure *d*. N.G.C. 7662

Figure *e*. N.G.C 7026

PLATE III.

For these stars we have, then, the relative radial velocities with reference to the Sun.

Since the Sun is known to be moving thru space, it is necessary to remove that part of the measured velocity due to the motion of the solar system, in order to obtain the radial speed of a star with reference to the great stellar system. Strange as it may appear, the first object in observing the velocities of all these stars was to determine the speed of the solar system, inasmuch as this important astronomical constant was unknown and could be obtained in no other way. The problem would be a very simple one if all of the stars were at rest, since then the measured velocities of the stars in the areas of the sky toward which and from which we are moving would give our speed at once. Inasmuch as none of the stars is at rest, the problem is much more complicated, requiring for its final solution a knowledge of the apparent velocities of recession and approach of a great many stars distributed over the whole sky. From such data, however, it is possible to obtain the speed and direction of the Sun's motion with reference to the system of the stars. Professor Campbell has found from a solution of the data, based upon the radial velocities of about 1200 stars, that the solar system is moving with a velocity of 12.3 miles per second toward a point in the heavens situated in the southern part of the constellation *Lyra*.

When the radial velocities of the stars and the gaseous nebulae with reference to the stellar system were finally obtained, he noted a most interesting fact. It was found that the velocities of the irregular gaseous nebulae were small, that the average space velocities of the blue, yellow and red stars were respectively about 8, 18 and 21 miles per second, while that of the planetary nebulae was about 48 miles per second. Altho we are not confident of the proper physical interpretation of this discovery, it undoubtedly is destined to play a very important role in all studies of stellar evolution.

Most of the stars whose radial speeds have been measured appear to be moving with a constant velocity, as they should do if not subject to any appreciable external force. In the case of about one-fifth of those observed the radial velocity is continually changing. The two spectrograms (Plate III a and b) are of the same star, *ι Pegasi*. They tell us that at the time of the first observation the star was approaching the Sun with a velocity of 31.7 miles per

second, whereas five days later, when the second plate was taken, it was receding with a velocity of 22.3 miles per second. Spectrograms of this star, secured on consecutive nights for an interval of a few weeks, show that the velocity change is continuous and periodic. In other words, the motion exhibited by this star is that which a star would have if it were revolving with a period of 10.2 days in an elliptic orbit whose plane is not at right angles to the line of sight. The existence of orbital motion for this star of course means the presence of a second star, the two revolving about their common center of mass in a period of 10.2 days. In the present instance the second star is too faint to record its spectrum, in the exposure-time used, but in many of these double stars the components are of about the same magnitude and we observe the periodic shifting of the lines of both spectra. The evidence of the spectroscope is very definite that stars of this class are double stars, altho, with two or three exceptions, spectroscopic binaries appear as single stars in the most powerful telescopes.

A number of years ago the great English physicist, Clerk Maxwell, demonstrated from the known laws of stable motion that the rings of *Saturn* could not be solid, liquid or gaseous in constitution, but that they must consist of myriads of separate particles. The conclusions reached from the mathematical viewpoint were later beautifully confirmed by Keeler from the interpretation of the spectrogram which he secured with the slit of the spectrograph placed along the apparent major axis of the rings. In Plate III c is reproduced a similar spectrogram of *Saturn* and its ring system, taken with the Mills spectrograph. The two outer strips of spectra (M) are of the Moon, the dark lines of which form convenient reference points. The central spectrum (S) is that of the planet *Saturn*, whose lines are strongly inclined in consequence of the rotation of the ball. That is, the western edge of the planet, which is receding, corresponds to the upper portion of the lines (displaced toward the red) whereas the eastern, or approaching, edge is represented by the end of the lines shifted toward the violet (left). The narrow spectra (R) between those of the planet and the Moon are from the ring system. In the upper (western) spectrum of the ring it will be noted that the speed of recession decreases as we pass outward in the ring. Similarly the velocity of approach decreases from the inner to the outer edge of the ring in the lower (eastern) spectrum. In other words, the interior

portions of the ring system are revolving more rapidly than the exterior ones, and hence the rings cannot be a rotating solid. The velocity at each point in the ring as indicated by these lines is that which a satellite would have at that distance from the planet; in short, the rings must be an aggregation of small satellites revolving around *Saturn*.

Professor Campbell and I have recently applied the same method of observation to the small disk-like images of the planetary nebulae, many of which are elliptical in form. When the slit of our spectrograph was placed coincident with the major axis of figure of the image the nebular lines were found to be inclined, while with the slit along the shorter axis, no inclination of the spectral line was observed. The very marked inclination of the N_1 line in the planetary N.G.C. 7026, with reference to the comparison line (long lines above and below) is shown in Plate III e. Our interpretation of the many messages of this character which we have obtained is that these planetary nebulae are rotating about axes approximately coincident with the shorter ones of figure.

In this investigation we received some messages from the planetaries of whose interpretation we are at present by no means certain. One of these is reproduced in Plate III d. The illustration is from a drawing of the planetary N.G.C. 7662. Above and to the right are placed photographs of the N_1 line obtained with the slit across the center of the nebula, along the two diameters, as indicated by the positions of the lines. The central portions of the lines are distinctly double in both cases, a fact which we have been unable to explain as a simple Doppler effect.

The light of that most interesting class of objects, known as the spiral nebulae, is unfortunately so feeble that the application of the spectroscope to their study is attended with considerable difficulty. It is necessary to be content with spectrograms obtained after many hours of exposure with a spectrograph of comparatively low power. The message is very definite, however, that their spectra are similar to those of the stars, and, with the exception of a few objects, contain no bright lines. Of the twenty-five spiral nebulae whose spectra have been observed by Dr. Slipher, at Flagstaff, three or four have velocities in the line of sight of as high as 600 miles per second. He has also shown by the method described above that the spirals are in very rapid rotation. As far as it goes the evidence of the spectroscope appears to point to a stellar con-

stitution of the spiral nebulae, and to velocities for them of a much higher order than that which is associated with objects in our galactic system. These facts, together with their great distance, and their peculiar avoidance of the Milky Way, have led to the suggestion that the spiral nebulae are other stellar systems, or "island universes."

One of the most difficult of all astronomical problems is the determination of the distances of the individual stars, since the base line which must be used, the diameter of the Earth's orbit, or 186,000,000 miles, is very minute in comparison with stellar distances. Hence the distances of comparatively few stars, altogether several hundreds, are known with any degree of certainty. Can the spectroscope come to our aid in the solution of this problem, as it has in so many others? Ten years ago I dare say that most astrophysicists would have regarded as forever beyond the realm of possibility a spectrographic method of determining stellar distances, and yet the recent work of Dr. Adams at Mount Wilson affords reason to believe that such a method has been found.

When the absolute brightness of a star, or that which it would appear to have if placed at unit distance from the observer, is known, we may readily compute the distance at which the star must be in order to give its observed or apparent brightness. From an examination of a number of spectra of stars of known distance Dr. Adams found that the continuous spectrum in the blue and violet was fainter for a star of great absolute brightness than for one which is known to be intrinsically faint, altho in other respects the spectra are of the same type. In addition he noticed that the apparent strength or intensity of certain dark lines in the spectra of stars of the same spectral class depends upon the absolute brightness of the star whose spectrum is observed. It was then possible, from the observation of the spectra of stars of known distance, to construct a scale representing the relation between the intensity of a given spectral line and the absolute brightness of the stars. For any other star of the same spectral type whose distance is to be determined, it is only necessary to measure the intensities of these particular lines in its spectrum, read off from the scale the corresponding absolute brightness of the star, and from this and its apparent brightness to compute the star's distance. The physical cause of the dependence of the intensities of certain spectral lines upon the absolute brightness of a star is not clearly understood

but the fact that the method gives results which are in close agreement with those determined by the usual trigonometric method, for the same stars, affords strong evidence of its validity.

I have attempted, this evening, to give you a glimpse, altho a hurried and imperfect one, of the great mine of information concerning the constitution, physical state, motions and distances of the stars contained in the spectrographic messages which have thus far been decoded. Many of the cipher-grams, on which is written the fascinating story of the origin and development of the new stars still await the code for their complete interpretation, and doubtless the significance of some of the messages which have been read will be more fully appreciated only when the evidence from many sources has been carefully considered. It is now scarcely more than half a century since the spectroscope was first successfully employed in the study of the stars, and yet so powerful and fruitful has this instrument proved in the hands of many skilful and tireless observers, that a whole new field of astronomical research has been developed, a field so new and at once so rich as to have well deserved the name of the "new astronomy."